UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MICROSTRIP RING RESONATOR FOR MEASUREMENT OF MOISTURE IN OIL PALM FRUITS AND SEEDS

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By

HAMEDA ALI ABRASS

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my dear mother, my dear father, my sincere husband, my cute daughters, your patients and support was my motivation

I love you all

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT OF A MICROSTRIP RING RESONATOR FOR MEASUREMENT OF MOISTURE IN OIL PALM FRUITS AND SEEDS

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Chairman : Zulkifly Abbas, PhD

Faculty : Science

The conventional oven method for the determination of moisture content in oil palm fruits and seeds is too laborious and time-consuming. An alternative method is to use microwave method, which is widely known to be accurate and rapid. However not all microwave techniques are suitable for single fruit or seed measurements due to small sample size. This thesis describes the development of a microstrip ring resonator to determine moisture content in oil palm fruits and seeds. The measurement system consists of the mirostrip resonator as sensor and PC-controlled vector network analyzer (VNA). This measurement software has been developed to control and acquire data from the VNA using Agilent Visual Engineering Environment Software. The microstrip ring resonator operates between 2.2 GHz and 3 GHz. The microstrip ring resonator operates at a low microwave frequency to allow wider electromagnetic field interaction between the resonator and the fruit sample. A theoretical analysis has been

carried out to establish the optimum operating frequency based on the relationship between the admittance and frequency of the microstrip ring. The propagation of electromagnetic wave is assumed to be transverse electromagnetic (TEM) mode. The actual moisture content was found by standard oven drying method. A calibration equation relating the measured and predicted values for both magnitudes (dB) of S_{11} and S_{21} was established. The equation was found to be accurate within 1.55% and 3.35% for the magnitude (dB) of S_{11} and S_{21}, respectively in the fruit samples. Similarly, the equation was found to be accurate within 2.89% and 3.38% for magnitude (dB) of S_{11} and S_{21}, respectively, in the seed samples. A calibration equation which relates the measured and predicted moisture content was also been established. The equation was found to be accurate within ± 2.7% for S_{11} and ± 2.9% for S_{21} for the fruit samples, whilst within ± 3% for S_{11} and ± 3.2% for S_{21} for the seed samples. The accuracy of this technique in determining the moisture content was tested on more than 160 different fruit and seed samples.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN RESONATOR CINCIN MIKROSTRIP UNTUK PENGUKURAN KELENGASAN DALAM BUAH DAN BENIH KELAPA SAWIT

Oleh

HAMEDA ALI ABRASS

Julai 2007

Pengerusi :Zulkifly Abbas, PhD

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Kaedah biasa menggunakan ketuhar untuk menentu kelengasan buah dan biji kelapa sawit memerlukan banyak tenaga manusia dan mengambil masa yang lama. Suatu kaedah pilihan ialah dengan menggunakan kaedah gelombang mikro yang dikenali ramai sebagai kaedah yang cepat dan tepat. Bagaimanapun, bukan semua teknik gelombang mikro sesuai untuk pengukuran buah atau biji benih kelapa sawit kerana saiznya yang kecil. Tesis ini menerangkan pembangunan alat resonan mikrostrip cincin untuk menentukan kandungan lembapan dalam buah dan biji benih kelapa sawit. Sistem ini terdiri daripada alat resonan mikrostrip cincin sebagai pengesan dan Penganalisa Rangkaian Vektor Berkomputer (VNA). Pengawalan dan pungutan butir maklumat daripada VNA dilakukan menggunakan perisian Aligent Visual kejuruteraan persekitaran. Alat resonan mikrostrip cincin ini beroperasi antara 2.2 GHz dan 3 GHz. Ia beroperasi pada frekuensi rendah gelombang mikro untuk membolehkan lebih banyak medan elektromagnet berinteraksi diantara alat resonan dan sampel buah atau bijibenih. Analisa secara teori dilakukan untuk mendapatkan nilai optimum frekuensi berdasarkan hubungan dianatar admitans dan frekuensi alat resanan ini. Perambatan gelombang adalah diperolehi melalui kaedah piawai pengeringan ketuhar. Persamaan penentukuran telah dibina menggunakan hubungan diantara nilai ukuran dan teori bagi S_{11} dan S_{21}. Persamaan adalah didapati tepat antara 1.55% dan 3.35% untuk magnetude (dB) S_{11} dan S_{21} untuk sampel buah. Untuk sample bijibenih, ketetepatannya ialah 2.89% dan 3.38% untuk S_{11} dan S_{21}. Persamaan penentukuran juga telah dibina menggunakan hubungan dianatar kelengasan yang diukur dan yang dijangka dengan ketepatan ± 2.7% dan ± 2.9% bila menggunakan S_{11} dan S_{21} untuk sample buah. Nilai sepadan untuk sampel bijibenih ialah ± 3% dan 3.2% menggunakan S_{11} dalam S_{21}. Ketepatan teknik dalam menentukan kandungan kelengasan ini telah diuji menggunakan 160 sampel buah dan lebih 160 sampel biji yang berbeza.

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I certify that an Examination Committee has met on 3rd July 2007 to conduct the final examination of Hameda Ali Abrass on her Master of Science thesis entitled "Microstrip Ring Resonator for Moisture Measurement of Oil Palm Fruits and Seeds" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Date: 13 September 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

HAMEDA ALI ABRASS

Date: 7 August 2007

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LIST OF ABBREVIATIONS/ SYMBOLS

Abbreviations

Agilent VEE	Agilent Visual Engineering Environment
ASCII	American Standard Code for Information Interchange
CAD	Computer-Aided Design
CBCPW	Conductor-Backed Coplanar Waveguide
DXF	Drawing Exchange Format
FFT	Fast Fourier Transform
FELDA	Federal Land Development Authority
FEM	Finite Element Methods
GPE	Gravitational Potential Energy
GPIB	General Purpose Interface Bus
HPIB	Hewlett-Packard Instrument Bus
I/O	Input/Output
MWG	Microstrip Waveguide
MPOB	Malaysia Polm Oil Board
OECWG	Open-Ended Coaxial Waveguide
PTFE	Polytetrafluorethylene (Teflon)
PC	Personal Computer
PORIM	Palm Oil Research Institute of Malaysia
PTFE	Polytetrafluoroethylene
RWG	Rectangular Waveguide

RDWG	Rectangular Dielectric Waveguide
SMA	Sub-Miniature A
TEM	Transverse Electromagnetic Mode
TE	Transverse Electric Mode
TM	Transverse Magnetic Mode
UV-Light	UltaViolet Light
VEE	Visual Engineering Environment
VNA	Vector Network Analyzer

Symbols

ε', ε_r'	real part of relative permittivity /dielectric constant
ε'', ε_r''	imaginary part of relative permittivity / loss factor
ε_{water}, ε_{fiber}, ε_{oil}	relative permittivity of water, fiber and oil, respectively
ε_{ri}	effective complex relative permittivity
ε_{rm}	effective complex relative permittivity of the mixture
ε_{eff}	effective permittivity
ε_r^*	relative complex permittivity
ε_o	permittivity of vacuum $(\mathrm{F/m})$
ε_{eff}'	effective dielectric constant
ε_{eff}^*	effective relative complex permittivity
ε_{water}, ε_{fiber}, ε_{oil}	relative permittivity of water, fiber and oil, respectively
v_i	volume fraction of the constituent in mixture model
v_{water}, v_{fiber} and v_{oil}	volume fraction of water, fiber and oil, respectively
ρ_{water}, ρ_{fiber} and ρ_{oil}	relative density of water, fiber and oil, respectively ($\mathrm{g/ml}$ or $\mathrm{g/cm^3}$)
m_{water}, m_{fiber} and m_{oil}	mass of water, fiber and oil, respectively (g)
$m.c.$	moisture or water content $(\%)$
m	molar mass (g / mole)
m ***before-dry***	mass of oil palm fruit before drying (g)
m ***after-dry***	mass of oil palm fruit after drying (g)

α_d	dielectric attenuation constants (dB/m)
j	square root of -1
ω	angular frequency (rad/s)
$\vec{B}$	magnetic flux density (W/m^2)
$\vec{E}$	electric field / electric intensity (V/m)
$\vec{D}$	electric flux density (C/m^2)
$\vec{H}$	magnetic field / magnetic intensity (A/m)
$\vec{J}$	surface current density (A/m)
ρ_q	linear charge density (C/m)
ε	permittivity (F/m)
μ	permeability (H/m)
σ	conductivity (S/m)
k_o	free space wave number (rad/m)
γ	propagation constant (m^{-1})
α	the attenuation constant
β	the phase constants
λ_o	free space wavelength (m)
ε_r	substrate permittivity
H_ϕ	azimuthal component of magnetic field for coaxial line (A/m)

$E_\rho^a, E_\rho, E(\rho)$	radial component of the aperture electrical field at radius ρ (V/m)
λ_g	guided wavelength (m)
n	number of wavelengths on the ring
λ	wavelength (m)
r	mean radius of the ring (mm)
f	frequency (Hz)
t	time (s)
T	temperature (^{0}C)
v_p	phase velocity
ρ	radius coordinates of point at aperture probe (m)
ϕ	angle coordinates of point at aperture probe (rad)
c	velocity in free space (m/s)
l_t	total length of the resonator (m)
R_{S1}	surface-roughness resistance of the conductor (Ω)
R_s	surface resistance of the conductor (Ω)
M	molar electric susceptibility
g	coupling gap (mm)
α_d	dielectric loss (dB)
h	substrate thickness (mm)
Ω	ohms
R_i	inner radius (mm)

R_o	outer radius (mm)
W, w	width of the microstrip (mm)
w_{eff}	effective width of the microstrip (mm)
l_e , l_0	artificial electrical lengths introduced by the even and odd impedances
Δ	surface roughness
$\varepsilon_{reff}(f)$	relative dielectric including the effects of dispersion
σ	conductivity of the microstrip
l_{ring}	physical length of the ring
λ_{ge} , λ_{go}	guided wavelengths to the even and odd resonance frequency, respectively
k	propagation constant (rad/m)
f_{re} , f_{ro}	measured odd and even resonant frequencies of the ring
Z, Z_{11} , Z_{12}	impedance parameters
Z_{in}	total input impedance (Ω)
°C	degree celsius
dB	decibel
%	Percent